



# **The Need and Challenges for Distributed Engine Control**

**GT2013-96081**

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ASME Turbo Expo 2013  
June 3-7, 2013, San Antonio, Texas, USA



# Outline

- Motivation for Distributed Engine Control
- Distributed Engine Control as a Solution
- How Distributed Engine Control Modifies Control System Thinking
  - Engine System – Control System Interaction
  - Control System – Impact of Control Architecture
- Summary



# Motivation

## Engine perspective

Need to improve performance

**Lower SFC:**

Compression Ratio

▶ Higher T4 ▶ Higher OPR

**Higher thrust/weight:**

Power Density of the Core

▶ Higher T4 + Higher aerodynamic performance

Higher temperatures – less space

## Controls perspective

Enables improved engine performance

- Tighter margins
- New control applications



Do more under increasingly severe environmental constraints ???

Electronics as a system vulnerability



# Motivation

## The Wider, Longer Term Outlook

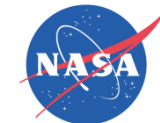
The engine depends on controls ... but *controls depends on electronics*

In the short term advances in electronics provide **more capability** in a **smaller volume** at **lower power**

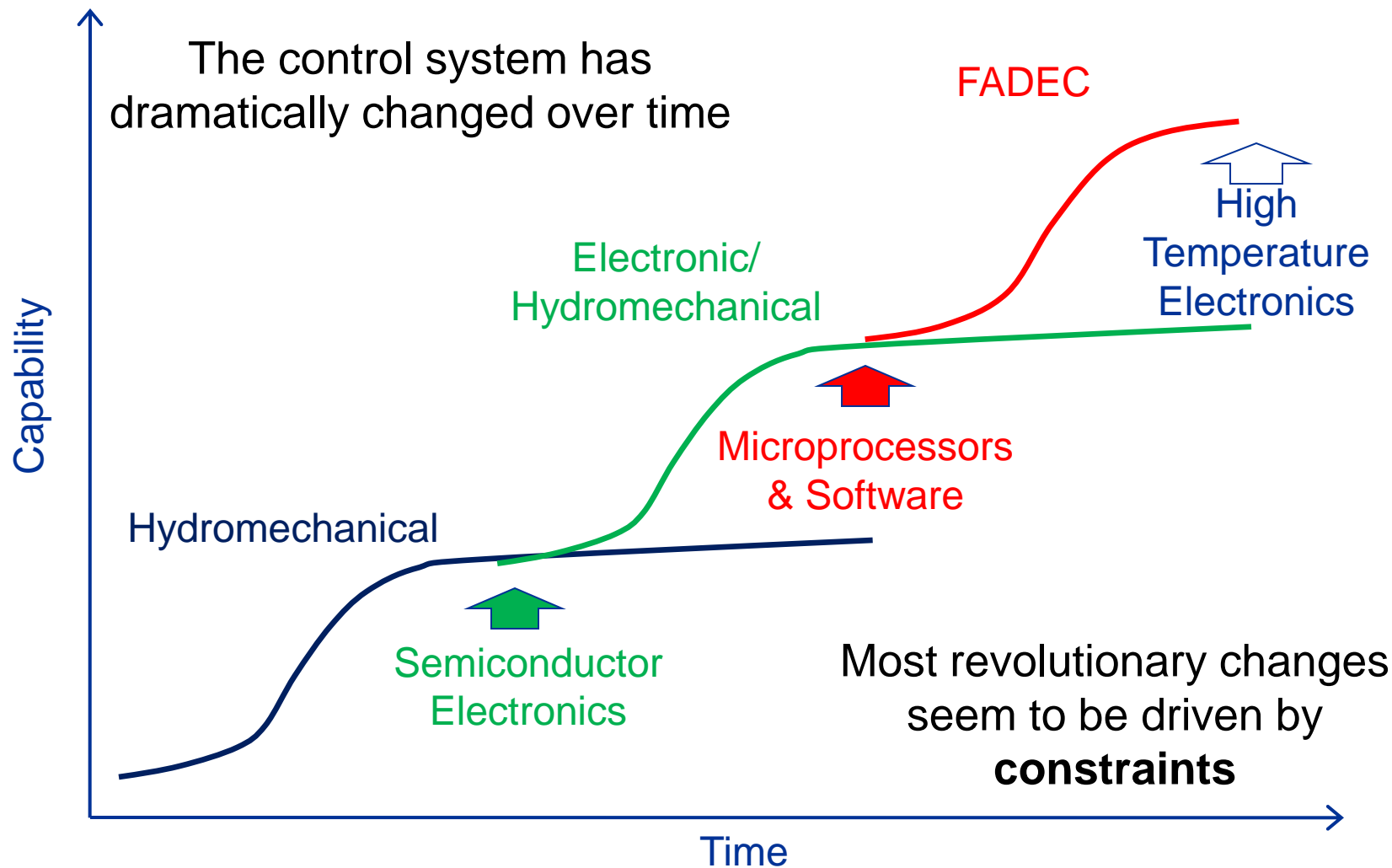
In the long term advances in electronics drive **more control system redesign** and **more re-validation, re-verification, and re-certification** to accommodate the obsolescence of electronic components

## Analogy

Imagine not being able to procure replacement turbine blades from any source for any price



# Gas Turbine Engine Control Architecture

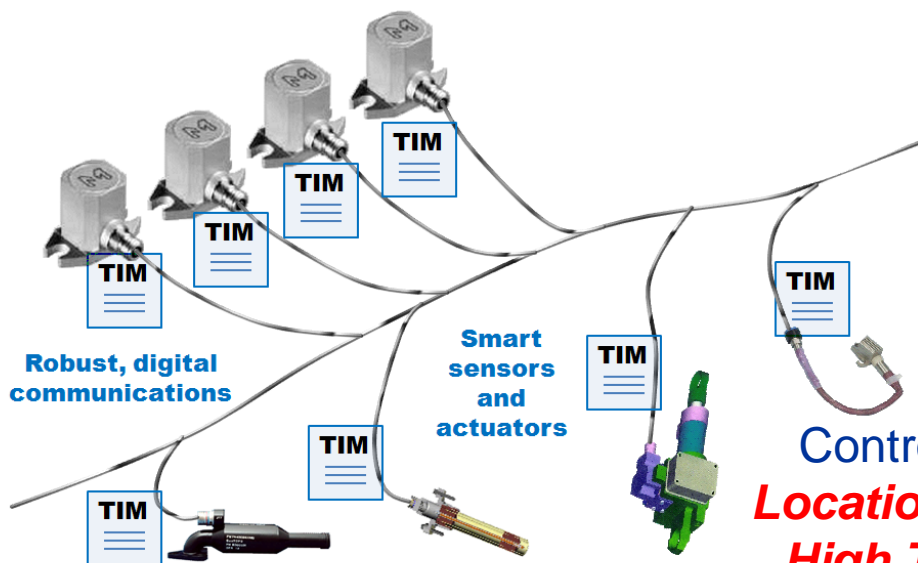


# Distributed Engine Control

New Capability that Directly Addresses  
Unique Constraints Imposed on the  
Control System

*based on*

Modular, Flexible, Scalable Control  
Architecture



Public release  
photo Intel.com

Processing-Intensive  
control functions based on  
commercial electronics are  
*Location Independent*

Control Effector functions are  
*Location Dependent* and require  
*High Temperature Capability*



# Revolutionary Change – Unique Challenges

**The turbine engine environment presents a more severe challenge to the fundamental operation of a distributed control system**

- Relative to automotive applications that use commercial components, higher temperature electronics being developed for the turbine offer a reduced capability in order to provide the necessary high reliability
- How do we safely apply this technology?
- How do we develop growth in its capability?
- Do we understand system design and system interactions?
- Can we effectively communicate these new requirements across the entire supply chain?

## Integration



# Engine System – Control System Interaction

Perception - Why *break* a perfectly good control system?

The engine is a complex system, its development is organized around highly specialized components – imperfect system knowledge

The control system is unusual - it interfaces to every part of the engine system.

- Direct – sensors and actuators
- Virtual - operation
- Hidden – e.g. wiring harnesses

Traditional Control Systems are highly affected by constraints and Control Engineers Traditionally Perform System Integration

- Engine system design
- **Control system design**
- **FADEC design**
- Software design



**Eliminate hardware dependencies**



# Control System – Impact of Control Architecture

High temperature electronics clearly enables **more distributed** engine control because processing functions become location independent

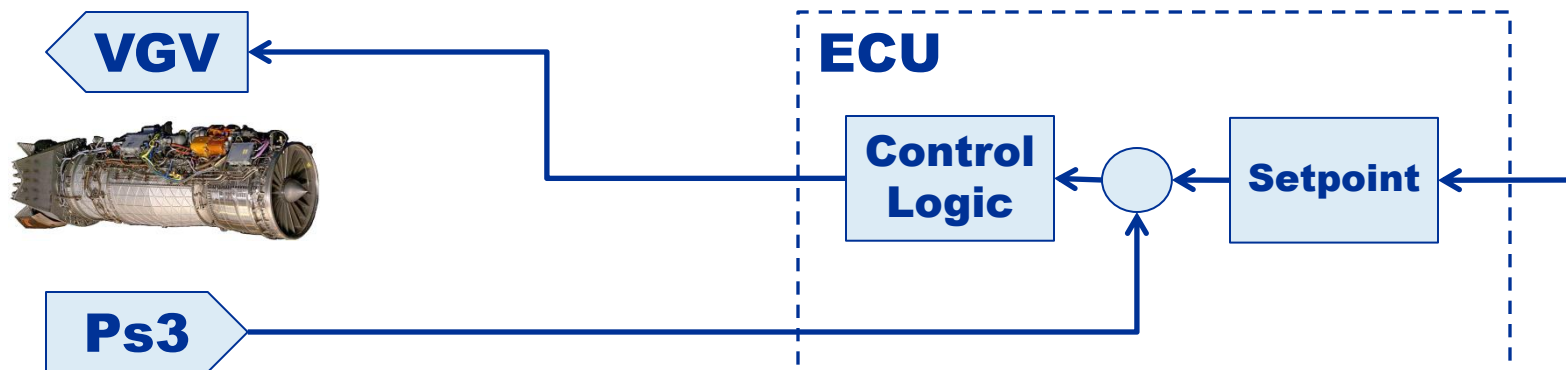


**Embedded Processing and analog functions at the Effector**



**Complex Processing in a more benign environment**

The control system integration focuses on **data flow** analysis between control elements





# Control System – Impact of Control Architecture

## Engine system integration

- Focuses on “**how to integrate the control system**” – a network issue
- Not “*how does control integrate with the engine system*” – a hardware issue



For example:

- A “smart” Ps3 sensor produces scaled, linearized pressure data in engineering units for direct use in the control system
- The device is integral to the compressor, not added
- The data is integral to the control system

This shift in approach opens up the possibility of simplifying the evaluation of new technology insertion at an earlier stage of development.

The potential for a smart Ps3:

- Compressor stability detection by sensing pip / modal pressure fluctuation
- Stability control by embedded FFT processing, control logic, and closed loop control of a stability actuator (bleed or flow control)

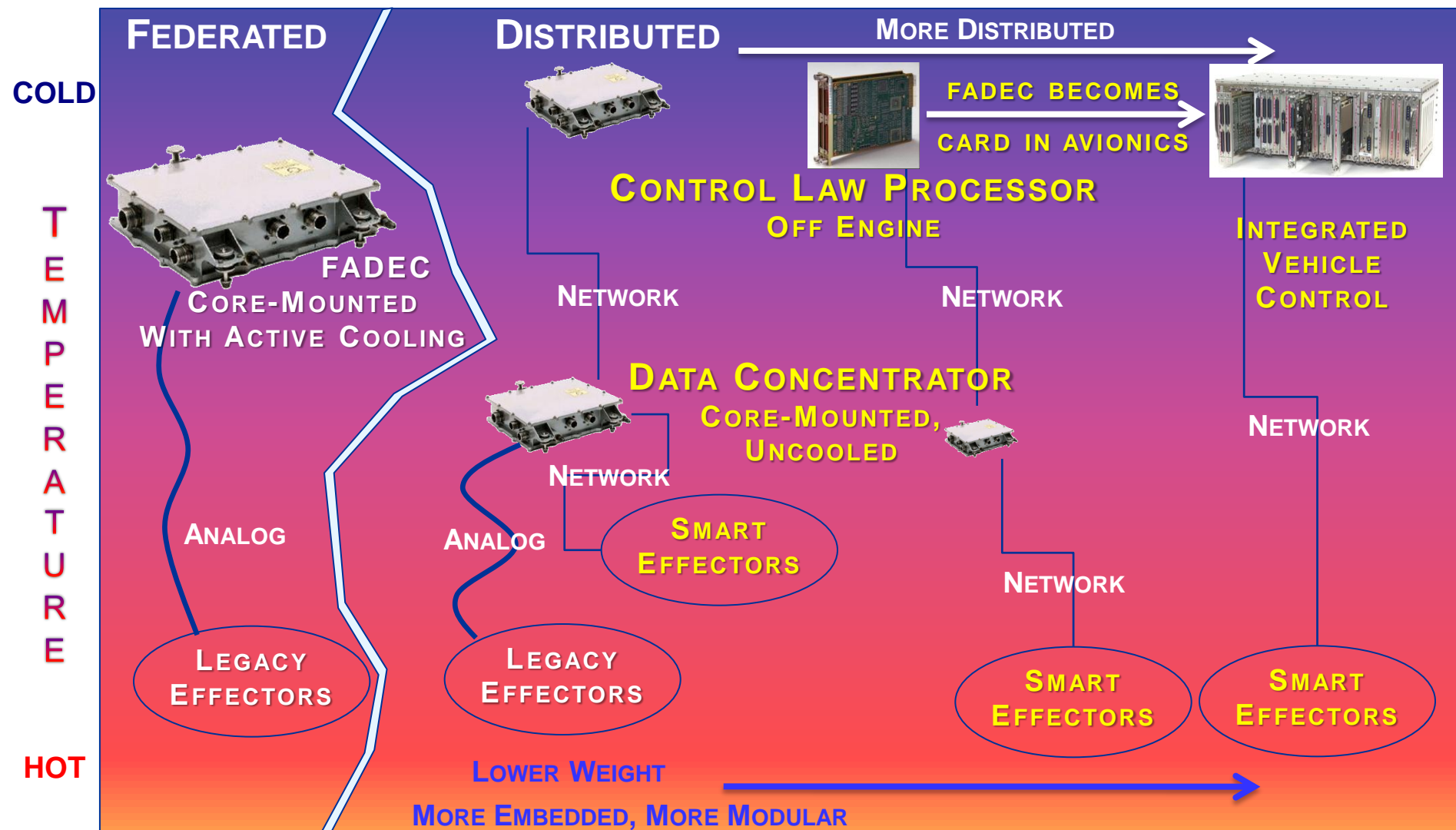


# Customers Don't Buy Technology, They Buy Capability

We need to be able to develop quantifiable metrics in terms that can be understood outside of the controls discipline

- Decision makers require information
  - Understanding of the benefits
  - Understanding of the constraints
  - Understanding the risk of
    - action – implementing new technology
    - Inaction – not implementing new technology

# The Evolution of Engine Control Architecture





# Summary

- Distributed Engine Control (DEC) is a revolutionary technology to alleviate engine system constraints on the control system.
- DEC offers significant potential to insert new beneficial control applications on the engine with reduced system impact.
- DEC drastically alters the engine integration environment and the supply chain.
- New tools are needed to fully understand DEC technology and to produce quantitative information for engine system decision makers regarding when and how to apply new control technology.



# Questions?



# Summary

- Distributed Engine Control (DEC) is a revolutionary technology to alleviate engine system constraints on the control system.
- DEC offers significant potential to insert new beneficial control applications on the engine with reduced system impact.
- DEC drastically alters the engine integration environment and the supply chain.
- New tools are needed to fully understand DEC technology and to produce quantitative information for engine system decision makers regarding when and how to apply new control technology.
- NASA and partners are developing comprehensive tools, for both simulation and control hardware, designed to understand and evolve DEC technology and to promote industry-wide collaborations toward the advancement of turbine engine capability.



# Integrated Tools

Distributed Control changes the nature of the entire supply chain

- System integrators (control engineers) no longer buy transducers and actuators – they buy **“smart components”**
- Suppliers need detailed understanding of functional requirements and interfaces necessary for seamless integration

Future control capabilities will evolve within these smart assemblies as well as at the engine system level – reflecting the nature of controls as **“a system of systems”**

There is a need for common control tools that tie everything together

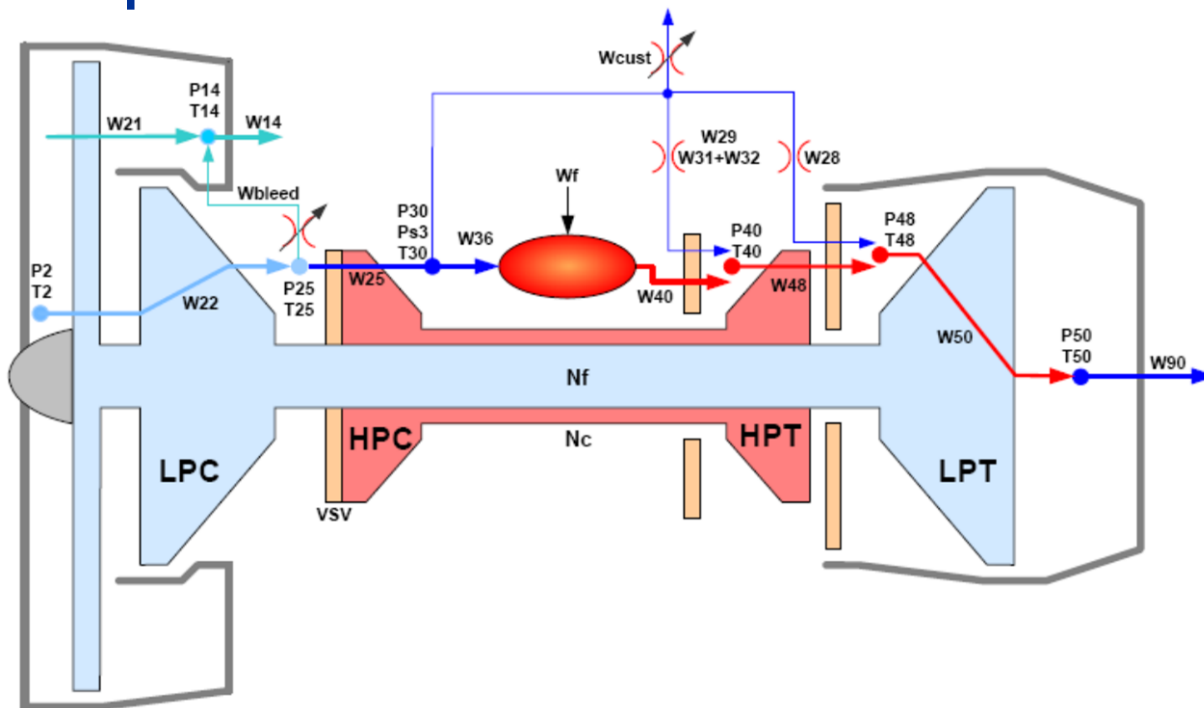
- From design to evaluation to verification
- From simulation to requirements development to hardware testing



# A Common Environment

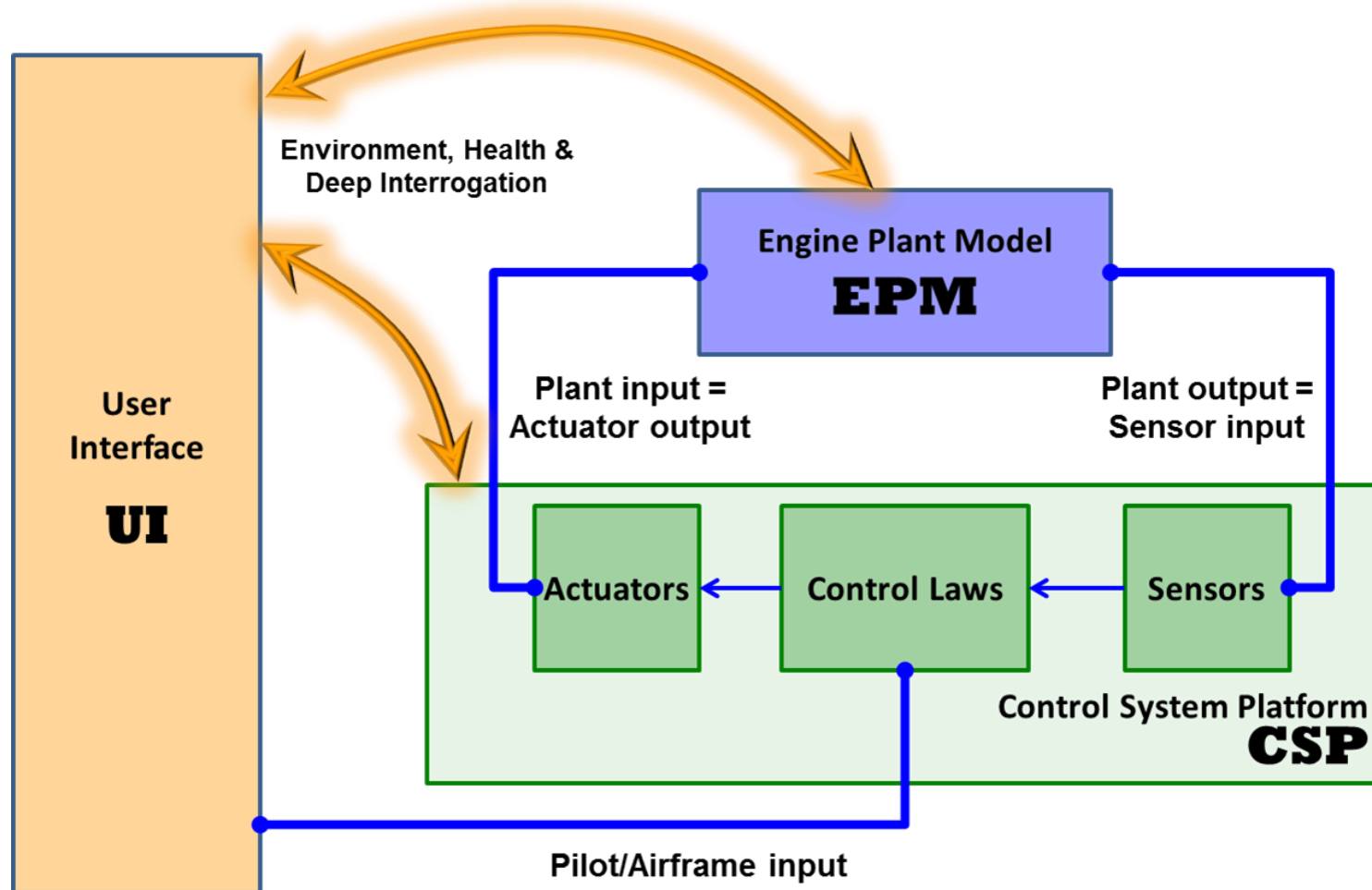
NASA is developing tools for controls development and integration with the intent of strengthening collaboration within the controls community.

The concept extends **C-MAPSS40k** to Hardware-in-the-Loop



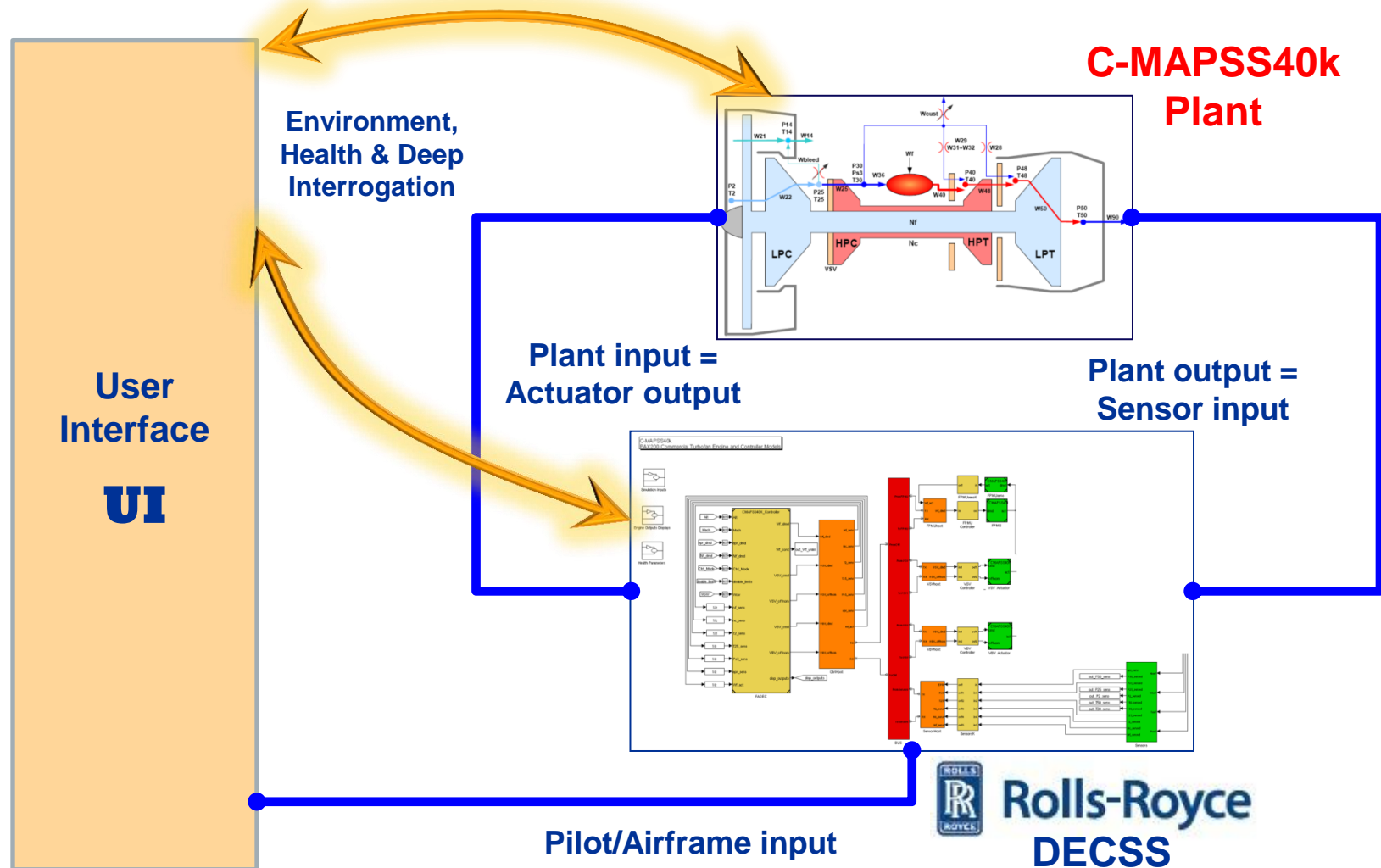
**C**ommercial **M**odular **A**ero-**P**ropulsion **S**ystem **S**imulation **40k** is a MATLAB/Simulink™ based *dynamic* simulation of a 40k-thrust class turbofan engine

# Hardware-in-the-Loop



The HIL system functions as a **virtual test cell** for performing investigations of control systems technology research & development.

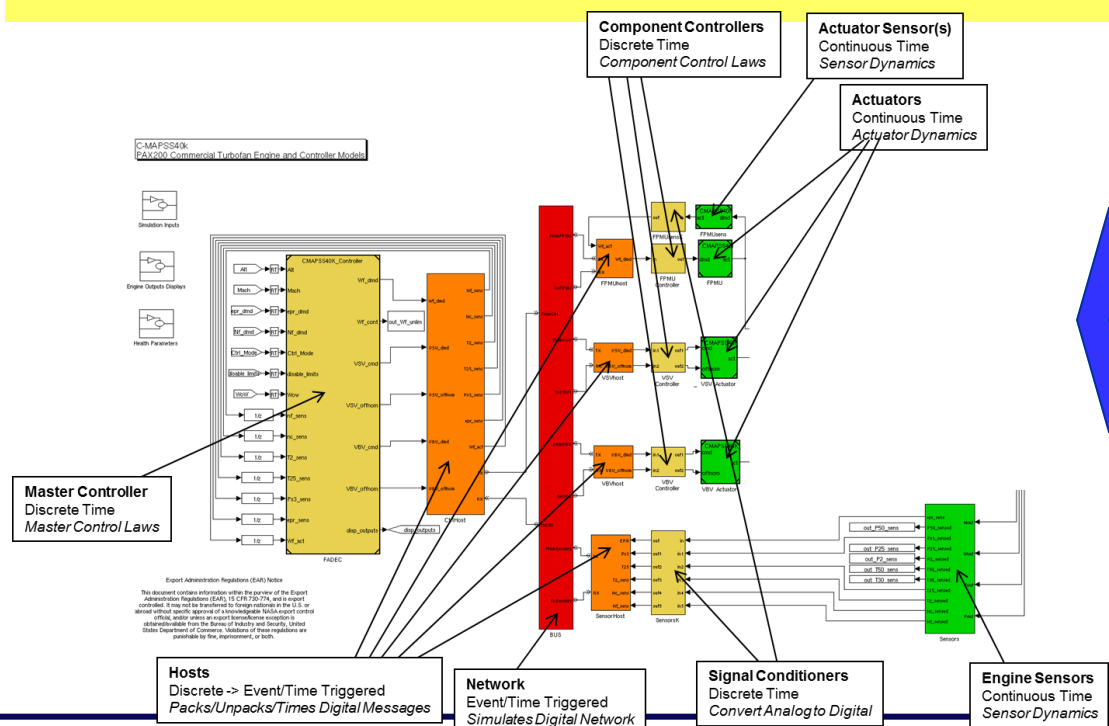
# Hardware-in-the-Loop



# Hardware-in-the-Loop Interfaces

In typical centralized control systems, the HIL system interfaces to a FADEC and the sensors and actuators are integral to the engine model

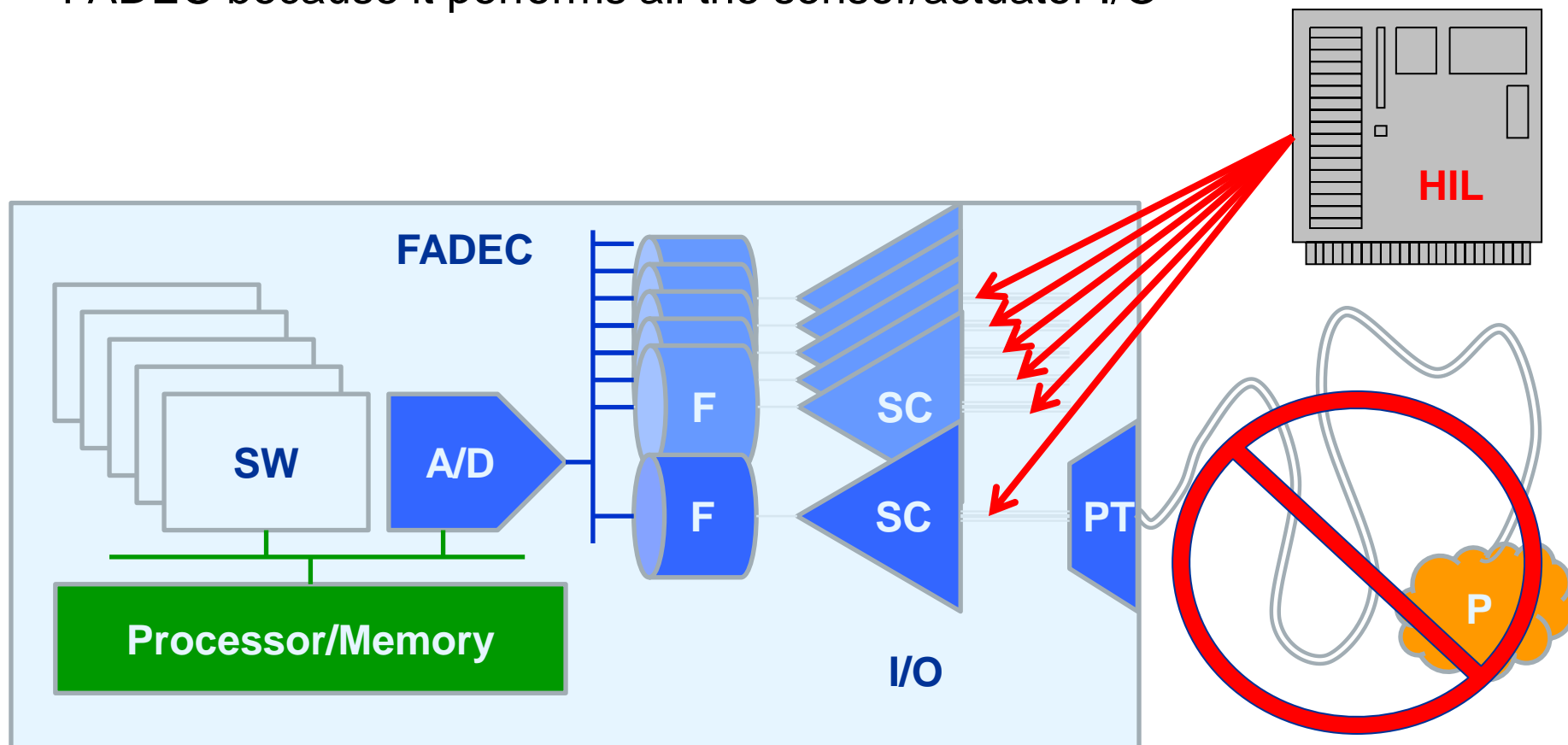
In distributed control, portions of the FADEC functionality are pushed into the sensor and actuators to create “smart” devices. The distributed control version of HIL needs to accommodate smart sensor and actuator hardware and bus structures as well as FADEC hardware.



**Rolls Royce  
Decentralized/Distributed  
Engine Control System  
Simulator  
is the basis of the  
Control System Platform**

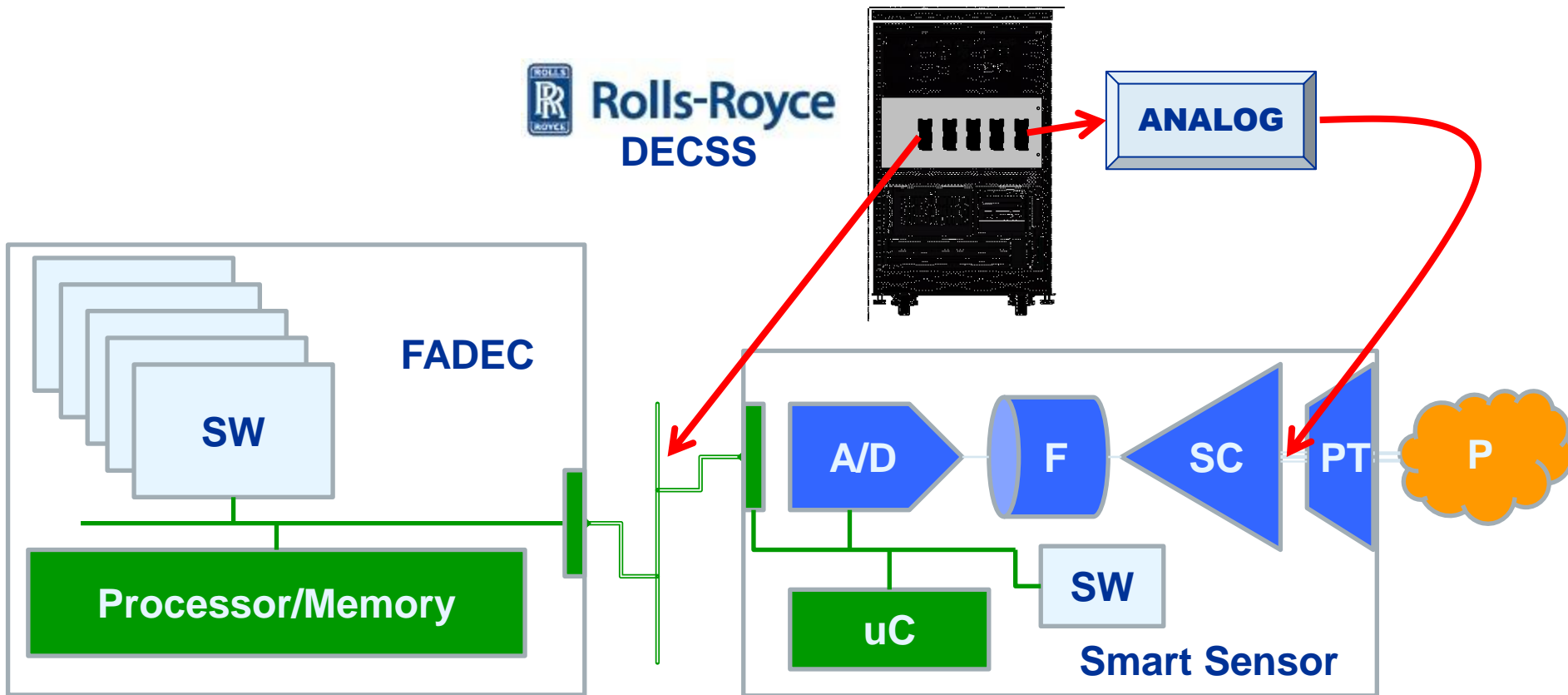
# HIL in a Centralized System

In typical centralized control systems, the HIL system interfaces to a FADEC because it performs all the sensor/actuator I/O



# HIL in a Distributed System

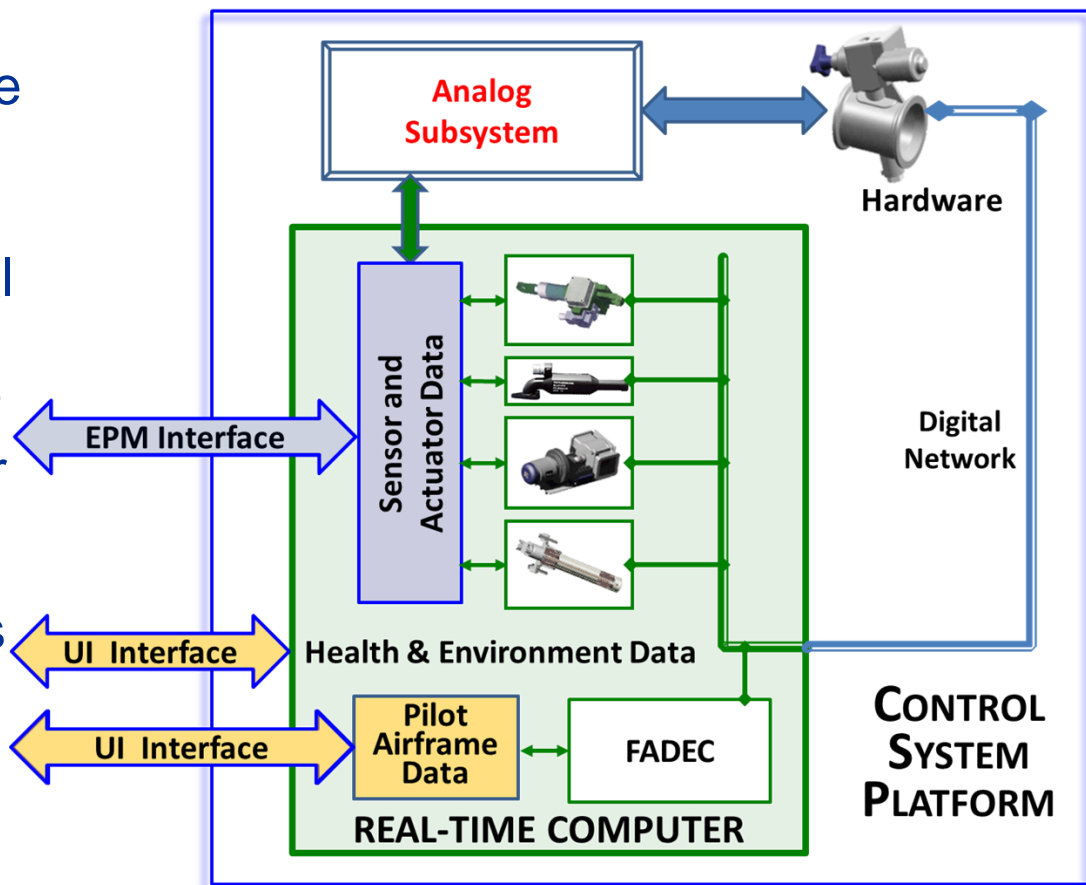
In a distributed control system, the HIL must interface to smart elements as well as the FADEC

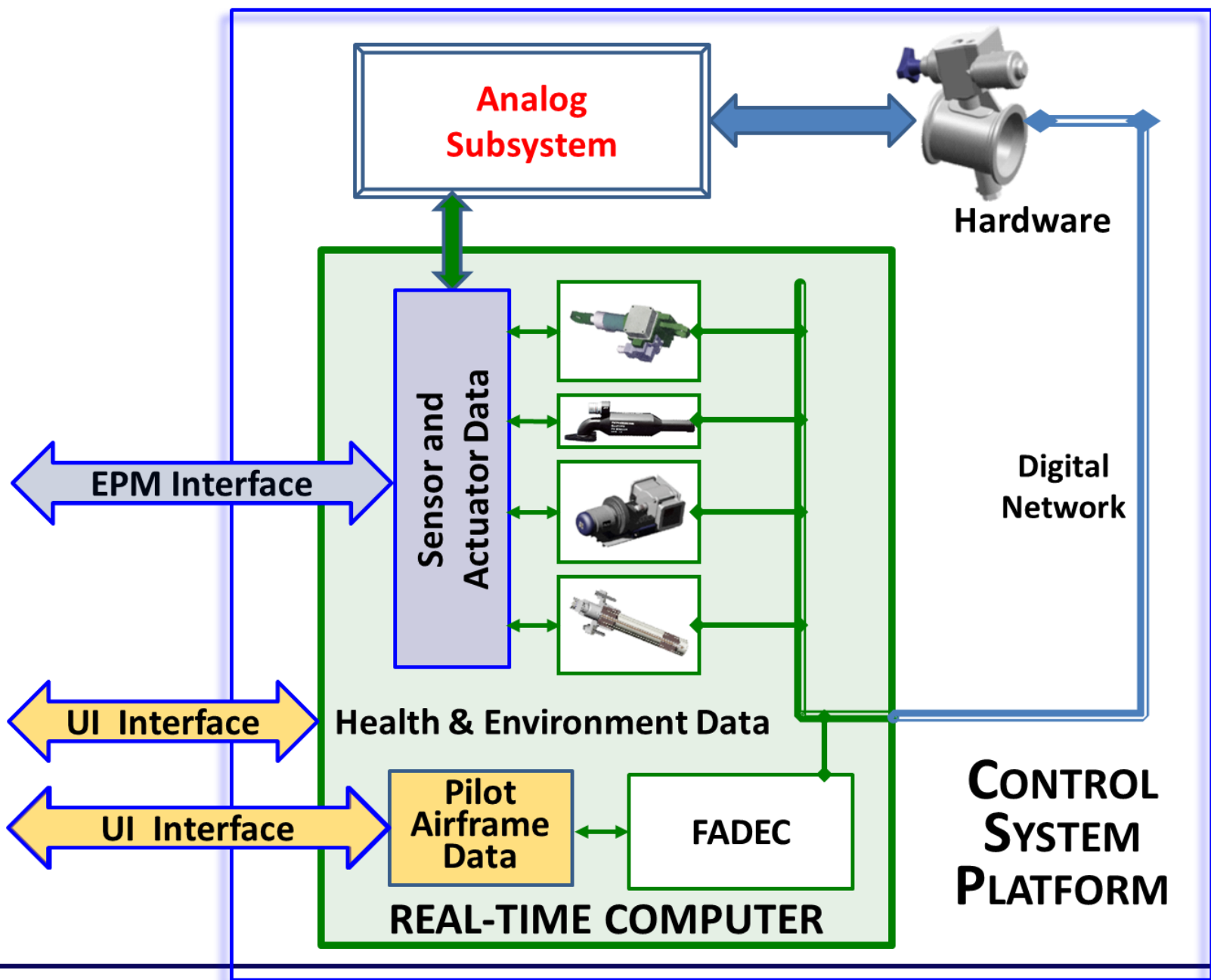


# Control System Platform

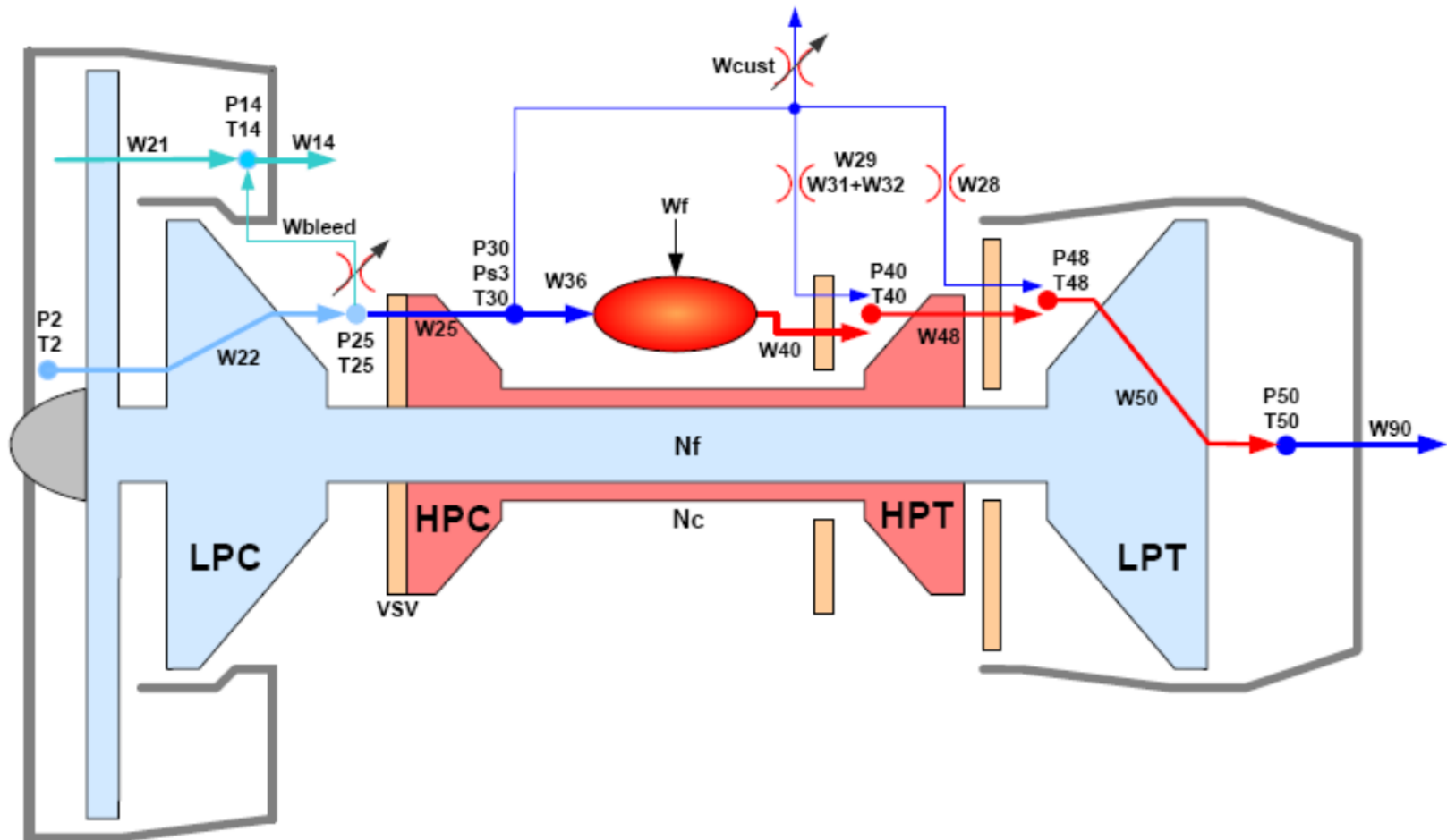
**Significant extensions** to the CSP, in the form of an analog subsystem, can enable it to generate electrical or physical analog interfaces compatible with the hardware versions of control elements, e.g., sensor stimulation.

These HIL system extensions might also be used to test hardware under relevant environmental conditions, e.g., temperature and vibration









# Distributed Engine Control

Developing New Capability for  
Engine Systems

*based on*

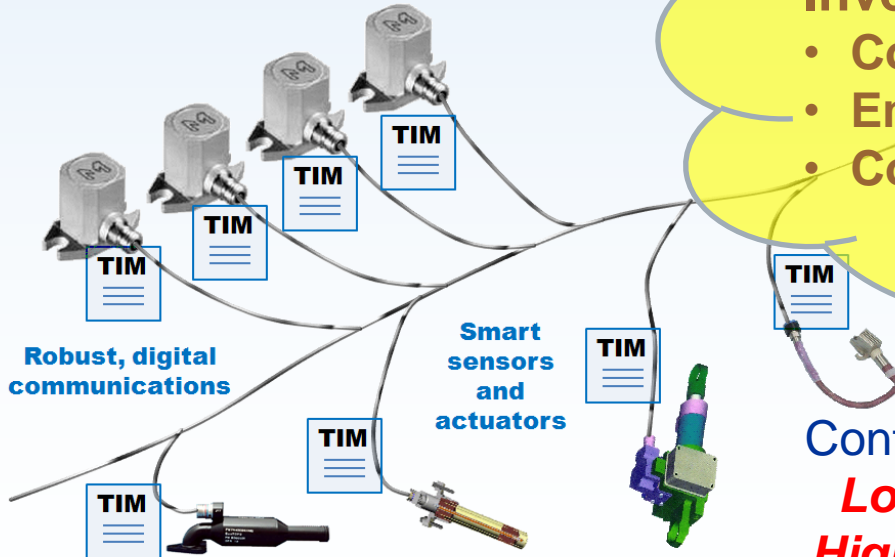
Modular, Flexible, Scalable  
Control Architecture

Processing-Intensive  
control functions are  
***Location Independent***



Simulation and Hardware-in-the-Loop  
Investigations of

- Control stability, performance & reliability
- Embedded high temperature design
- Control / Engine / Airframe integration



Control Effector functions are  
***Location Dependent*** and  
***High Temperature Capable***

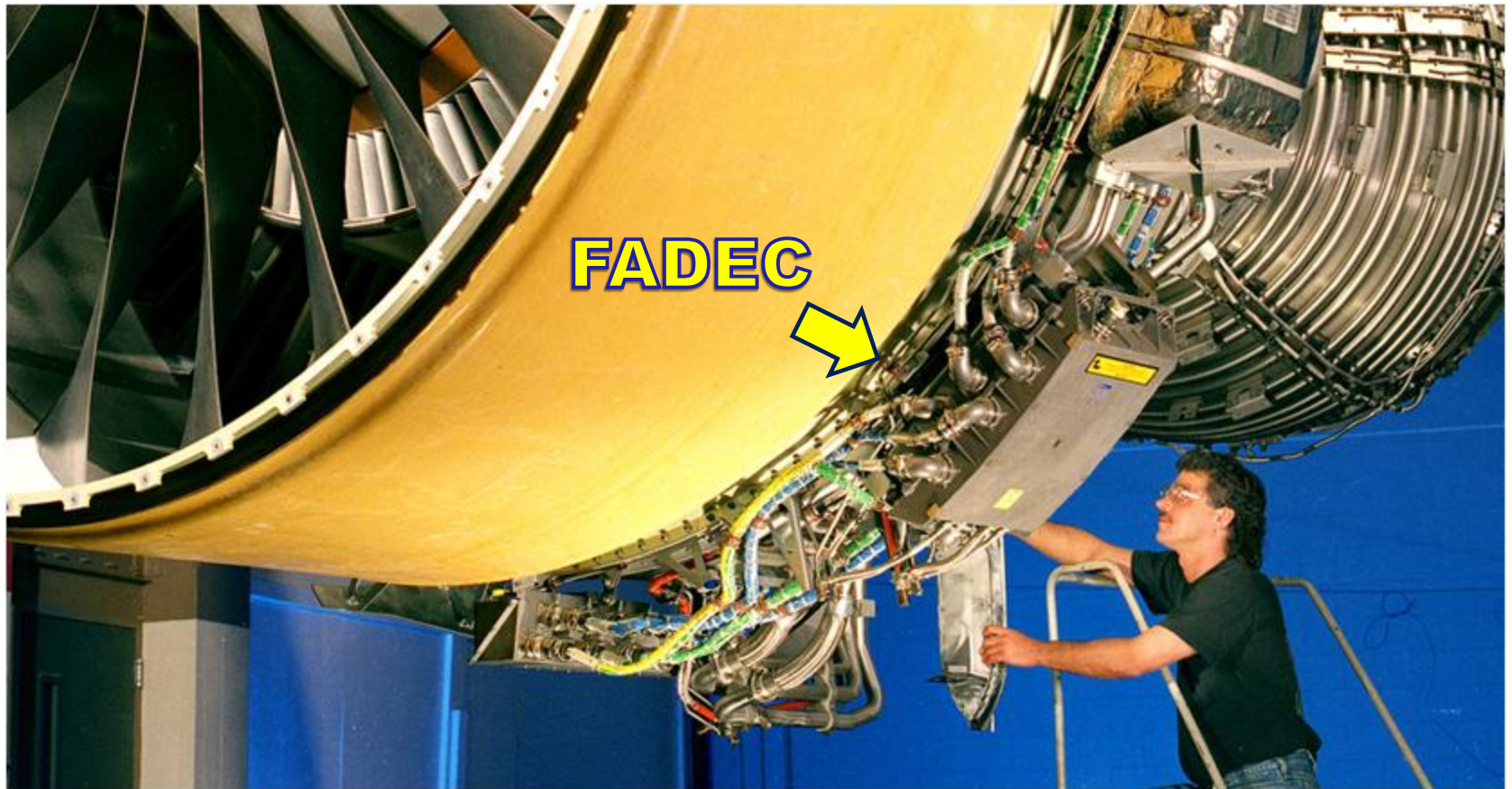
Glenn Research Center

at Lewis Field



# Commercial Control Implementation

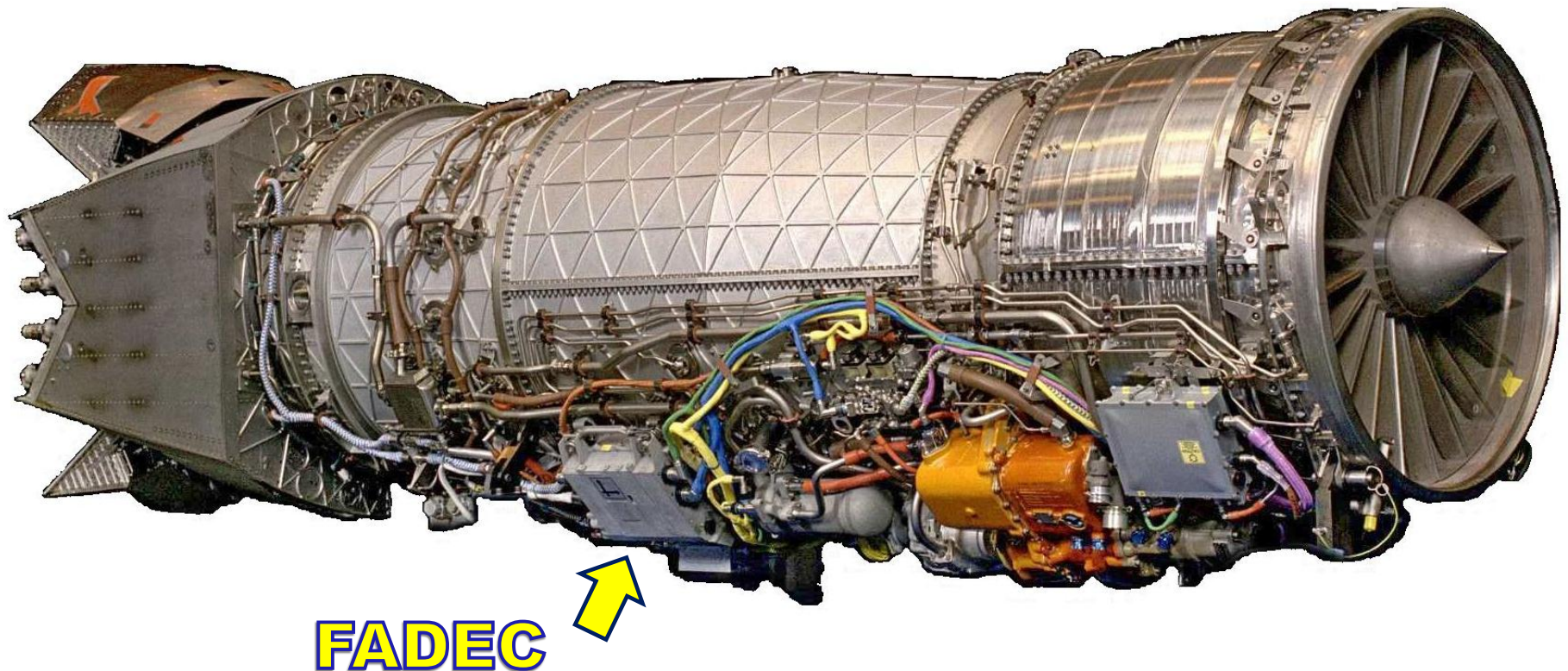
## Fan Case Mounted - Air Cooled





# Military Control Implementation

Core Mounted - Fuel Cooled



**FADEC**